Optical "Antimatter"

Scientists at Berkeley Lab's Molecular Foundry led by Stefano Cabrini, working in collaboration with colleagues at the Institute for Microelectronics and Microsystems (IMM) in Naples, have, for the first time, experimentally demonstrated optical "antimatter," which allows light to travel through a material without being distorted, thus allowing improved resolution in images made with that light. The work was reported in the April 3, 2009 issue of *Physical Review Letters* and was depicted on its cover.

For years, optics researchers have struggled to overcome the "diffraction limit," a physical principle that restricts imaging resolution to about one-half the wavelength of the light used to make the image. Theoreticians have predicted that a material with a negative "index of refraction," would allow resolution below the diffraction limit and could be used in a "superlens," which would form images with detail finer than otherwise achievable. Materials with a negative index of refraction were, however, thought to be inaccessible (air has an index of near 1, water 1.33, glass 1.5, etc.).

In the mid-1990s, English theoretical physicist Sir John Pendry proposed that metamaterials – artificially engineered composite materials with properties, such as a negative refractive index, not attainable with naturally occurring materials – could be made. These would have an underlying structure that would allow control of their response to electrical and magnetic fields. Inspired by Pendry's proposal, scientists have worked to create these materials in the laboratory. The first of these operated with light in the microwave frequency range. Progress is now being made in extending performance to the infrared and visible region.

Through the Molecular Foundry user program Vito Mocella of the IMM, who designed a new metamaterial composed of alternating layers of air and silicon with an effective refractive index of zero, collaborated with Foundry scientist Cabrini, to fabricate that material. Using high-precision nanofabrication techniques available at the Foundry's Nanofabrication facility, the design was realized in a "photonic crystal," which has a periodicity similar to that of the atomic lattice in crystalline solids. In optical testing, the shape of a laser beam was fully preserved as it passed through the sample for a distance of 2 mm, more than 1000 times its infrared wavelength of 1.55 micrometers. This is the first explicit experimental verification of optical "antimatter" in which a negative refractive index material (in this case, the silicon photonic crystal) appears to cancel out or "annihilate" the effect of an equal thickness layer of air.

Work at the Foundry is continuing to find a geometry and material that will produce this optical antimatter effect for visible light. Along with applications in imaging, the researchers' findings could also be used to develop hybrid negative- and positive-index materials, which may lead to novel devices and systems unachievable through the use of either material alone.

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V. Mocella, S. Cabrini, A. S. P. Chang, P. Dardano, L. Moretti, I. Rendina, D. Olynick, B. Harteneck, and S. Dhuey, Self-Collimation of Light over Millimeter-Scale Distance in a Quasi-Zero-Average-Index Metamaterial, Phys. Rev. Lett. 102, 133902 (2009)

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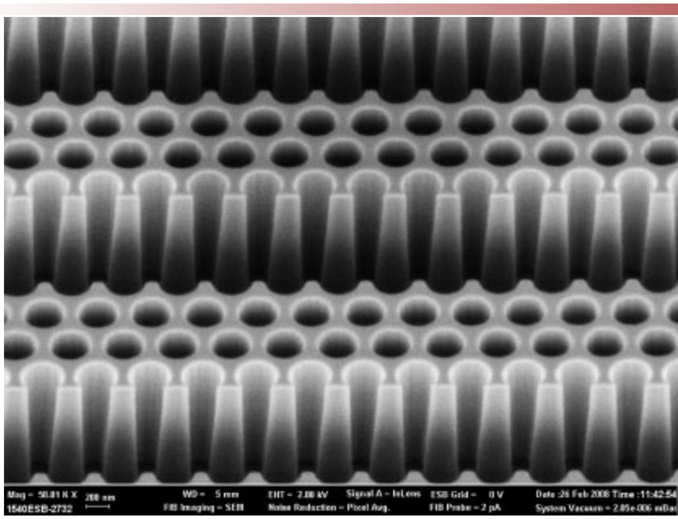
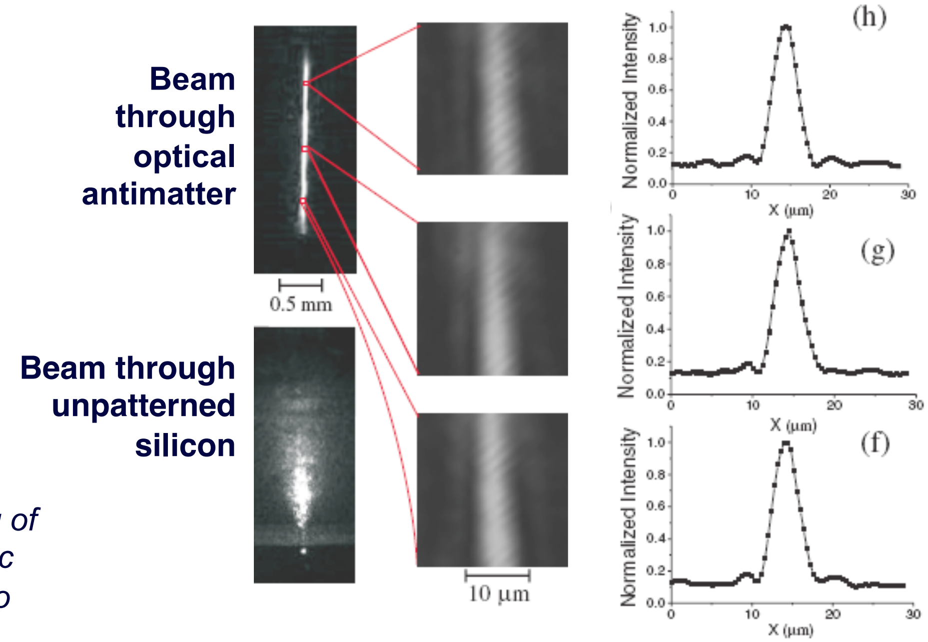
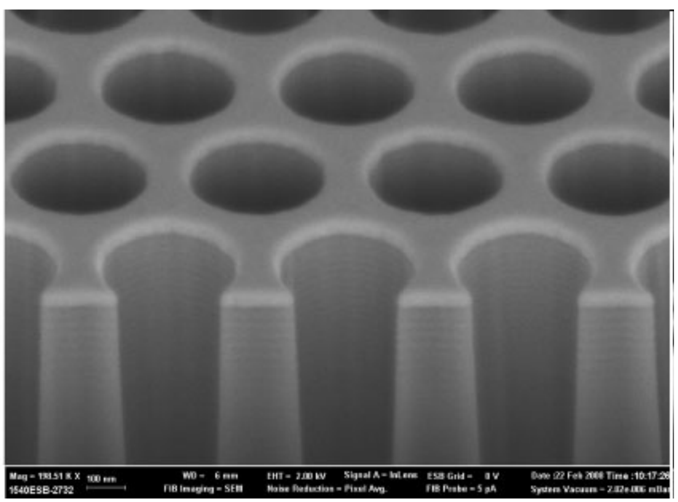
Optical Antimatter





LBNL's Molecular Foundry fabricated *a structure consisting of alternating bands of a negative refractive index silicon photonic crystal (detailed below) and air. The structure was designed to form a "metamaterial" with an overall refractive index of zero.*



Laser light propagating *through unpatterned silicon (bottom left) spreads due to diffraction effects. Light propagating through the "metamaterial" (upper left, center, and right) does not spread. This demonstrates the optical antimatter effect in which a negative refractive index material (the silicon photonic crystal) appears to appears to “annihilate” an equal thickness layer of air.*

V. Mocella, S. Cabrini, A.S.P. Chang, P. Dardano, L. Moretti, I. Rendina, D. Olynick B. Harteneck, S. Dhuey, *PRL*, **102** 133902 (2009).